

REACTIVE STIMULATION OF OIL AND GAS WELLS

[0001] This application claims the benefit of the filing date of provisional application serial number 60/502,703, entitled "Reactive Stimulation of Oil and Gas Wells," filed September 12, 2003, the contents of which are incorporated herein by
5 reference.

FIELD OF THE INVENTION

[0002] The present invention relates to methods and devices for stimulating producing formations in oil and gas wells to increase production.

BACKGROUND OF THE INVENTION

10 [0003] The quantity of oil and gas production from a hydrocarbon bearing strata into a borehole is influenced by many physical factors. Darcey's flow equation, which defines flow in a well, takes into account the reservoir constants of temperature, viscosity, permeability, reservoir pressure, pressure in the borehole, thickness of the producing strata, and the area exposed to flow.

15 [0004] It has long been known that increasing the exposed flow area in a producing well increases production. For example, it is known that drilling a larger diameter hole exposes more of the producing strata and thus increases production.

[0005] Enlarging the flow areas, in open hole intervals, has been accomplished by using both explosives and chemicals. However, use of these agents is somewhat limited
20 where the producing strata are cemented behind steel casing. In cased applications, the well is "perforated" to create small holes that extend through the steel casing, the annulus cement and the adjacent formation.

[0006] Prior to the invention of the shaped charge, wells were perforated with multiple, short-barreled guns. The bullets penetrated the casing, the annulus cement, and the producing strata. The shaped charge, with its greater penetration and reliability, though, has largely replaced the so-called "bullet guns."

5 [0007] A shaped charge makes a hole through the casing and into the strata by forming a high speed stream of particles that are concentrated in a small diameter jet. As the high energy particles hit solid material, the solid material is pulverized. Thus, shaped charges can be used to place numerous small perforations where desired in a well. However, the fine material from the pulverized rock and the shaped charge particles can
10 have a detrimental effect on fluid flow in the area around the perforation. Debris from the spent charge as well as fragments and particles from the pulverized formation tend to plug the perforations and obstruct passages in the fractured formation.

[0008] The formation pressure acts on the small oil droplets in the formation to force the hydrocarbons from the connected pore spaces into the well bore. The
15 magnitude of the area in the formation exposed by the perforations directly affects the amount of flow and/or work required for that production. Accordingly, increasing the exposed flow area by perforation does two favorable things: it increases the flow rate directly, and, it reduces the amount of work required to maintain a given production rate. Increasing the flow area in a well increases the ultimate recovery from the well/reservoir
20 by conserving formation pressure or reservoir energy.

[0009] The present invention provides a method and apparatus capable of increasing the exposed surface area in a formation when using shaped charges to perforate a well. This apparatus and method augment the use of shaped charges by

including the introduction of oxygen rich material into the formation with the explosive. The delivery of an oxygen source to the hydrocarbon-containing formation, in the presence of the explosive reaction, provides sustained explosive burning of the hydrocarbons in the vicinity of the perforation. The burning in the formation continues
5 until the oxygen-rich material is depleted, when the burning self-extinguishes. Thus, the extent of the burning can be controlled by selecting the amount of oxygen-rich material to be introduced into the formation.

[0010] This significant secondary reaction in the strata has two beneficial effects. In the first place, the reaction will cause a cleaning effect on the fine particles that might
10 otherwise plug the perforation. The cleaning effect occurs when the explosive burning causes high pressure gases to be generated, and these pressurized gases are discharged rapidly back into the borehole or casing. Secondly, the extended burning or explosion in the treated stratum causes further fracturing of the formation. This results in further expansion of the exposed flow areas in the formation beyond the initial shaped charge
15 perforation. In addition, in the event the strata being perforated are water bearing, the explosive reaction will not occur; rather, only oil or gas bearing formations will be stimulated.

SUMMARY OF THE INVENTION

[0011] The present invention is directed to apparatus for stimulating production
20 from a hydrocarbon-containing formation in an oil or gas well. The apparatus comprises a container sized to be received and supported in the well at a level adjacent the formation. At least one shaped charge is supported within the container. The shaped charge is adapted, when ignited, to perforate the formation and to initiate a burn of

hydrocarbons therein. The apparatus includes a supply of oxygen-rich material supported within the container and adapted to be introduced explosively into the formation with the shaped charge. In this way, the burn of hydrocarbons therein is extendable. The apparatus further includes at least one igniter for detonating the shaped charge.

- 5 [0012] Still further, the present invention comprises a method for stimulating production from a hydrocarbon-containing formation in an oil or gas well. The method comprises perforating the formation using a shaped charge and introducing an oxygen-rich material to the formation. Thus, the burn of the hydrocarbons is enhanced.

BRIEF DESCRIPTION OF THE DRAWINGS

- 10 [0013] Figure 1 is a longitudinal section view of an apparatus in accordance with a first embodiment of the present invention. The apparatus is shown positioned at the level of a target formation in an oil or gas well.

[0014] Figure 2 is a schematic diagram illustrating the timing of the sequence of events produced by the apparatus of Figure 1.

- 15 [0015] Figure 3 is a fragmented sectional view of the target formation shown in Figure 1 after completion of the stimulation treatment.

[0016] Figure 4 is a longitudinal sectional view of an apparatus in accordance with a second embodiment of the present invention positioned at the level of a target formation in an oil or gas well.

- 20 [0017] Figure 5 is a section view of a shaped charge made in accordance with one embodiment of the present invention.

[0018] Figure 6 is a section view of a shaped charge made in accordance with another embodiment of the present invention.

[0019] Figure 7 is a section view of a shaped charge made in accordance with another embodiment of the present invention.

[0020] Figure 8 is a section view of a shaped charge made in accordance with another embodiment of the present invention.

5 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The Embodiment of Figures 1-3

[0021] With reference now to the drawings in general and to Figure 1 in particularly, there is shown therein an apparatus constructed in accordance with a first preferred embodiment of the present invention and designated generally by the reference
10 numeral 10. The apparatus 10 is adapted to stimulate production from a hydrocarbon-containing formation or strata 12 in an oil or gas well 14.

[0022] An illustrative well environment is shown in Figure 1 and comprises shale zones 16 and 18 above and below the formation 12. In most instances, the apparatus 10 will be used in a cased interval of the well 14, and the casing of the well 14 is indicated at
15 20 with the cement in the annulus designated at 22.

[0023] The apparatus 10 comprises a container 24 sized to be received and supported in the well 14 at a level adjacent the formation 12. Preferably, the container 24 is elongated having first and second ends 26 and 28.

[0024] The apparatus 10 further comprises at least one shaped charge supported
20 within the container 24. The shaped charge is adapted, when ignited, to perforate the formation. Preferably, there is a plurality of shaped charges that can be positioned to perforate different locations in the formation 12. More preferably, there are three shaped

charges, such as the charges 30. This embodiment may use conventional shaped charges. Accordingly, no detailed description of the shaped charges 30 is provided herein.

[0025] With continuing reference to Figure 1, an igniter of some sort is provided to detonate the shaped charges 30. In the preferred embodiment of Figure 1, the igniter
5 comprises an electrical igniter 32 disposed within container 24. The igniter 32 is electrically connected to a conductor wire 34 which extends from the apparatus 10 to the well head (not shown). As shown here, the conductor wire 34 may be used to suspend the apparatus 10 in the well 14.

[0026] Extending from the igniter 32 is a primer cord 38. Preferably, the primer
10 cord comprises a high order explosive, and is crimped into and made a part of the igniter 32. The primer cord 38 connects to the shaped charges 30 in series. Thus, when the igniter 32 is initiated by a signal from the surface through the conductor wire 34, the shaped charges 30 will be ignited by the fast burning primer cord 38, which runs from the igniter 32 to the uppermost shaped charge 30 in the plurality of charges.

15 [0027] Referring still to Figure 1, the apparatus 10 preferably also includes a supply of oxygen-rich material supported within the container 24 and adapted to be introduced explosively into the formation 12 with the shaped charges, such as the charges 30. This will provide a source of oxygen to support explosive burning of the hydrocarbons in the formation.

20 [0028] In the embodiment of Figure 1, the oxygen-rich material 40 in the container 24 is external to and surrounds the shaped charges 30. Preferably, the oxygen-rich material 40 is potassium nitrate. However, the other materials such as ammonium

nitrate may be utilized in addition to or instead of potassium nitrate. As used herein, "oxygen-rich material" denotes any material capable of releasing oxygen when activated.

[0029] To propel the oxygen-rich material 40 through the perforations behind the shaped charges 30, the apparatus is provided with separate delivery explosives in the form of end charges 44 and 46. The end charges 44 and 46 preferably are composed of a slow burning (low order) explosive and may be positioned at the first and second ends 26 and 28, respectively, of the container 24. When thus arranged, it is convenient to attach the primer cord 38 to the end charges 44 and 46, as shown in Figure 1. Thus, a single signal on the conductor wire 34 to the igniter 32 will ignite the end charges 44 and 46 as well as the shaped charges 30 via the primer cord 34.

[0030] The end charges 44 and 46, positioned at each end of the supply of oxygen-rich material 40, will create very high pressures momentarily inside the container 24 and the well casing 20. This pressure will force the oxygen-rich material 40 out through the perforations in the casing 20, the annulus cement 22, and into the surrounding formation 12 immediately behind the shaped charges. This in turns causes explosive burning of the hydrocarbons in the formation 12 that is supported by the oxygen being released by the oxygen-rich material 40.

[0031] The operation of the apparatus of Figure 1 is explained with reference to the diagram in Figure 2. At Time Zero, the signal from the conductor wire 34 triggers the igniter 32 (Figure 1), which in turn initiates the explosive reaction in the fast burning primer cord 38 that runs the length of the container 24. The reaction time of the igniter 32 is shown at 50 on the time graph in Figure 2. The spike has a duration of about 0.0500 milliseconds, and the total reaction time of the igniter is about 0.200 milliseconds.

[0032] The igniter 32 initiates the reaction in the fast burning primer cord 38. Being a fast burning explosive, the cord 38 burns from the igniter to the cord end very rapidly, for a duration of about 0.500 milliseconds indicated at 52 in Figure 2. The preferred primer cord 38 burns at about 20,000 feet per second. Thus, the primer cord 38
5 could travel a 10-foot string of 40 shaped charges, for example, in only about 0.500 milliseconds.

[0033] The primer cord 38 ignites the shaped charges 30, the oxygen-rich material 40, and the low order explosives in the end charges 44 and 46. Due to fast burning (high order) explosives in the shaped charges 30, the shaped charges burn rapidly
10 for about 0.100 milliseconds as indicated at 54. However, the much slower burning oxygen-rich material 40 and the end charges 44 and 46 burn for a much longer duration, about 4.000 milliseconds and about 5.000 milliseconds at 56 and 58, respectively.

[0034] Referring still to Figure 2, the secondary reaction in the formation comprising the sustained burning of the hydrocarbons lasts until the oxygen-rich
15 material 40 is depleted, as indicated at 60. The total duration of the reactive explosion of hydrocarbons and oxygen in the formation, therefore, begins shortly after the introduction of oxygen in the perforated hole and into the formation and expires as the pyrotechnic reactions stop for lack of oxygen or other reagents.

[0035] The effect of the operation of the apparatus 10 is illustrated in Figure 3, to
20 which attention now is directed. This drawing illustrates the condition of the well after ignition of the apparatus 10. The container 24 and its components are substantially destroyed, leaving perforations 62 corresponding to the positions of the shaped charges 30. The sustained, explosive burn of the hydrocarbons in the formation

surrounding the perforations 62 has substantially increased the surface area for production by fracturing and cleaning the formation.

The Embodiment of Figures 4-6

[0036] Shown in Figure 4 is another preferred embodiment of the apparatus of the present invention. In this embodiment, the apparatus 10A comprises an elongated container 24A having first and second ends 26A and 28A. The container 24A is suspended by a conductor wire 34A similar to the corresponding components of the apparatus 10 of Figure 1. An electrical igniter 32A, which may be similar to the igniter 32 of the previous embodiment, is supported near the first end 26A of the container 24A.

[0037] At least one and preferably three shaped charges 70 are supported inside the container 24A. As in the previous embodiment, the shaped charges 70 preferably are connected in series to a primer cord 38A, which is connected to the igniter 32A. Generally, it is desirable to average about four shaped charges per foot.

[0038] The apparatus 10A also includes a supply of oxygen-rich material. However, in this embodiment, the oxygen-rich material is contained in the shaped charges 70.

[0039] One preferred embodiment for the "oxygenated" shaped charge 70 of this invention is shown in Figure 5 and designated as 70A. The shaped charge 70A comprises a body of high explosive 72 formed to have a conically shaped frontal recess 74.

[0040] A detonator is included in the shaped charge 70A to ignite the body of explosive 72. The detonator may be the primer cord 38A running therethrough.

[0041] A liner 76, usually of copper, is included. The liner 76 is shaped to line the frontal recess 74 in the body of explosive 72. Thus, the liner 76 in this configuration is conical.

[0042] Still further, a layer of oxygen-rich material 78 is included in the shaped charge 70A. In the preferred form, the oxygen-rich layer 78 is positioned between the conical copper liner 76 and the conical frontal recess 74 of the body of explosive 72. The conically shaped oxygen-rich material 78 and the conically shaped copper liner 76 thus form a bimetallic liner for the shaped charge 70.

[0043] After the primer cord 38A ignites the high explosive 72, the rapid burning of explosive 72 will convert the conically shaped copper liner into a rapidly moving jet that will perforate the casing and the formation (neither shown in this Figure). At the same time, the conically shaped oxygen-rich layer 78 will also be converted into a slower moving slug of oxygen-rich material. This slower moving slug follows the rapidly moving jet into the formation where, in the presence of the jet and the hydrocarbons in the formation, the oxygen-rich slug will support an extended burn of the hydrocarbons.

[0044] Shown in Figure 6 is another embodiment of a shaped charge in accordance with the present invention designated as 70B. In this embodiment, the shaped charge 70B comprises a conically shaped body of fast burning explosive 80. The recess 82 is also conical in shape. A detonator is included, such as the primer cord 38A, to ignite the fast burning explosive 80.

[0045] The shaped charge 70B further comprises a conically shaped insert 84 of slower burning (lower order) explosive. The insert 84 is shaped to conform to and be

received in the frontal recess 82 of the body 80. Thus, the insert 84 in the embodiment shown is conically shaped. Further, the insert 84 is shaped to have a planar front 86.

[0046] Referring still to Figure 6, the shaped charge 70B comprises a disc shaped layer 88 of fast burning explosive. The fast burning layer 88 has a front 90 and a rear 92.

5 The rear 92 is fixed to the planar front 86 of the insert 84.

[0047] Still further, the shaped charge 70B includes a disc shaped layer 98 of elastic material molded at high pressure to contain an oxygen-rich material, such as potassium nitrate fixed on the front of the fast burning layer 88.

[0048] It is now seen that, when the shaped charge 70B is detonated, the
10 oxygen-rich disk 98 will be propelled through the casing 20 and cement annulus 22. The initial movement of the disc of oxygen-rich material 98 will be ahead of the shaped charge jet. However, the shaped charge jet will quickly pierce the disc of oxygen-rich material 98 and will proceed to make the perforation through the casing 20 and cement annulus 22. The solid oxygen-rich disk 98 becomes a projectile that follows the jet into
15 the perforation tunnel. The disk 98 supports the combustion of hydrocarbons in the formation ignited by the jet for the selected duration.

[0049] Turning now to Figure 7, another embodiment of the "oxygen-loaded" shaped charge will be described. This embodiment, designated generally by the reference numeral 70C, comprises a first body 100 of fast burning explosive formed to have a
20 frontal recess 102. Preferably, the frontal recess 102 is generally conical in shape and the apex is curved or domed instead of pointed.

[0050] Also included is a body of oxygen-rich material 104, such as potassium nitrate, formed to be received in the frontal recess 102 of the first body of explosive 100

and to have a frontal recess 106. The frontal recess 106 has a cylindrical center portion 108 and a frusto-conical forward portion 110.

[0051] Still further, the shaped charge 70C comprises a second body 112 of fast burning explosive shaped to conform to and be received in the cylindrical center 108 of the recess 102 in the body of oxygen-rich material 104. The second body 112 is also shaped to have a conical front recess 114 continuous with the frusto-conical forward portion 110 of the frontal recess 106 in the body of oxygen-rich material 104. In this way, the frontal recess 114 of the second body of explosive 112 and the frusto-conical portion 110 of the frontal recess 106 in the oxygen-rich material 104 form a complete cone.

[0052] The charge 70C includes detonators, such as the primer cords 38A and 38B, adapted to ignite the first body of fast burning explosive 100 and the second body of fast burning explosive 112. A conically shaped metal liner 118 is positioned inside the complete cone formed by the frontal recess 114 of the second body of explosive 104 and the frusto-conical portion 110 of the frontal recess 106 in the oxygen-rich material 104.

[0053] The primer cords 38A and 38B ignite the first and second bodies of fast burning explosives 100 and 112. Then, second body of high order explosive 112 will collapse the liner 118 to form a high velocity jet which will penetrate the casing, cement, and formation. Concurrently, the first body of high order explosive 100 propels the oxygen rich material 104 into the perforation tunnel in time to support the reaction of the jet and the hydrocarbons in the formation.

[0054] With reference now to Figure 8, yet another embodiment of a shaped charge will be described. This shaped charge, designated generally as 70D, comprises a

body of fast burning explosive 120. The body of explosive 120 is formed to have a stepped frontal recess 122 with a conical center portion 124 and a frusto-conical forward portion 126. The narrowest diameter of the forward portion 126 forms a step 128 between the center portion 124 and the forward portion 126.

5 [0055] The charge 70D further comprises a body of oxygen-rich material 130 formed to be received in frusto-conical forward portion 126 of the frontal recess 122 of the body of explosive 120. The narrowest diameter of the body of oxygen-rich material 130 is substantially the same as the widest diameter of the center portion 124 of the frontal recess 122 of the body of fast burning explosive 120. Thus, the conical center
10 portion 124 of the frontal recess 122 of the body of explosive 120 and the body of oxygen-rich material 130 form a complete cone.

[0056] A detonator, such as the primer cord 38A is adapted to ignite the body of fast burning explosive 120. Also, included is a conically shaped liner 132 positioned inside the conical center portion 124 of the frontal recess 122 in the body of fast burning
15 explosive 120.

[0057] The primer cord 38A ignites the body of fast burning explosives 120. Then, the liner 132 and a small part of the oxygen rich material 126 will collapse into a high velocity jet that will penetrate the casing, cement, and formation. The remaining oxygen rich material 126 will form a slower moving slug that will enter the perforation
20 tunnel in time to support the reaction of the jet and the hydrocarbons in the formation.

[0058] In accordance with the method of the present invention, there is provided a method for stimulating the hydro-carbon containing strata in an oil and gas well. First, preferably using one of the above described apparatus, the formation is perforated using a

shaped charge. An oxygen-rich material, such a potassium nitrate, is introduced into the formation to support a sustained burn of the hydrocarbons therein.

[0059] Whether the apparatus 10A with the shaped charge 70B is employed or the shaped charge 70A is utilized or the apparatus 10 of Figure 1 is used, the oxygen-rich
5 material is forced into the formation following the shaped charge jets. In all cases, though, a supply of oxygen-rich material is dispersed through the altered formation in the presence of ignited hydrocarbons so that a sustained burn can occur. This effectively increases the exposed surface area and enhances production from the altered formation.

[0060] Changes can be made in the combination and arrangement of the various
10 parts and elements described herein without departing from the spirit and scope of the invention as defined in the following claims.